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PSR 0656+14, PSR 1055-52 and Geminga: The Softest X-ray Emitting, Isolated Neutron Stars

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The investigations receiving funding have described the wealth of detailed information on high energy objects. In particular, the study of an eclipsing polar, DP Leo, and a possible intermediate polar, TT Ari, have yielded significant results.

For DP Leo, we have found (Robinson & Cordova 1994) that:

(1) The temperature of the soft X-ray region on the surface of the white dwarf has been constrained with the emission arising from a fraction of the white dwarf's surface much smaller than the previously observed cyclotron and UV blackbody emission regions.

(2) The distance to DP Leo has been constrained by the photoelectric absorption to be 500 pc or less. An estimate based upon the magnitude of the secondary provides a distance of 260 (+150, -100) pc.

(3) An intensity dip is observed prior to eclipse. The likely origin is absorption of the emission region on the surface of the white dwarf by an accretion stream which is varying in its position, relative to the secondary, with time.

(4) The X-ray light curve is highly variable showing no emission outside of the bright phase, sinusoidal or little emission prior to the intensity dip, and flare-like emission after eclipse. This suggests that the soft X-ray accretion region may be inhomogeneous with respect to accretion rate per unit area.

(5) X-ray emission was occurring at only one pole in the ROSAT data from 1992. Our modeling suggests, however, that two pole X-ray emission was likely occurring at the time of the EINSTEIN observations in 1979.

(6) A soft X-ray excess exists showing that the soft X-rays are produced primarily from a mechanism other than the reprocessing of bremsstrahlung emission. The great variability observed in soft X-rays, not seen in optical light curves, suggests that the origin is more likely filament accretion.

(7) The magnetic pole of the white dwarf currently rotates slightly faster than the orbital period. This motion may be produced by an oscillation in the position of the magnetic pole of the white dwarf with respect to the secondary star. In addition, the eclipse period observed in DP Leo is longer than the actual orbital period due to the accretion region longitude variations. Magnetic activity induced distortion of the secondary star may be producing both oscillations in the orbital period and the difference between the orbital and white dwarf rotation periods.

(8) A model for the accretion stream is developed assuming initially a ballistic trajectory for the stream and disrupting the stream flow close to the white dwarf surface. This model explains the structure of red light emission within the eclipse.

Models of the magnetic fields in polars may be constrained in the future by determining the shape of the accretion flow close to the white dwarf surface perhaps through combined X-ray, optical emission line and cyclotron emission observations of high inclination systems. Mechanisms producing the complex magnetic fields observed in cataclysmic variables and single white dwarfs may be constrained through the determination of the field structures. In addition, a slightly longer observational baseline is needed to constrain whether the origin of the asynchronous rotation of the white dwarf is produced by orbital period variations or through oscillations in the position of the magnetic pole.

The unusual source TT Ari shows (Robinson et al. 1997): This investigation into the X-ray behavior of TT Ari determined that:

(1) The system is variable on numerous time scales with modulations near 836's being the most prevalent in the *Ginga* data set. The origin of this modulation may be the spin of the white dwarf or the mechanism producing the decay in the optical QPO periods.

(2) Orbital modulations of X-rays exist but were only detected in the ROSAT energy range at only a modulation level of around 5%. This is consistent with a relatively small portion of the soft X-ray photons arising due to reprocessing off a fixed structure in the binary system, likely either the hot spot or the photosphere of the secondary. It is, however, still possible that the modulation is produced by absorption. Larger amplitude modulations observed with Einstein were produced at times of increased X-ray emission. This is consistent with increased reprocessing at the time of increased X-ray flux.

(3) A QPO at 8.3's was apparent in both the *ROSAT* and *Ginga* data sets. Additional, simultaneous QPO's at other frequencies are also possible.

(4) Absorption events do not appear historically in X-rays at a preferred phase nor do they repeat at regular intervals.

(5) In addition to the absorption events, there exists a hardness dependence with X-ray count rate. In the Ginga energy range, the system gets significantly softer at low count rates.

(6) The spectrum agrees with a bremsstrahlung continuum with two emission lines.

(7) The observed X-ray flux does not correlate well with the optical state. Rather, the X-ray flux appears increased in the intermediate optical state as compared with the high optical state.

If the 836's modulations are related to the spin of the white dwarf, then TT Ari belongs to the class of CVs known as intermediate polars. The hard X-ray spectrum it possesses and the X-ray modulation at the orbital period are consistent with this class of objects. However, the lack of an energy dependence in the amplitude of the 836's modulation is not consistent with the behavior of most intermediate polars nor with current theory. Nevertheless, since the QPO's found in TT Ari on times scales of order \$10^3\$ sec are always near to or longer than 836 sec, if the 836 modulation is found to be the white dwarf spin period, this may allow upper limits to be placed upon the spin periods of other, similar systems (e.g., KR Aur, V795 Her, H0551-819, V603 Aql, etc.).

If the 836's modulation is a signal related to the decreasing optical QPO's, then the mechanism producing the QPO's is further constrained. Arguments in favor of this interpretation include the agreement between the detected period and that predicted from the history of QPO periods, the similarity between the X-ray light curves and those observed for the QPO in the optical, and the correlation between optical and X-ray fluctuations found in several studies.

Finally, since evidence continues to build that the secondaries in several cataclysmic variables show high levels of magnetic activity, it is increasingly important for models of these systems to include the effects of this activity and the variations it produces. These obviously include the effects of mass accretion through the secondary's stellar wind, the effect of the varying magnetic field of the secondary on the accretion flow, the disk, the internal structure of the secondary, and the interaction between white dwarf and secondary magnetic fields.

Robinson, C.R. & Cordova, F.A. (1994) ApJ, 437, 436
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